WHAT ARE THE PHYSICAL CHARACTERISTICS OF THE DISTAL TIBIA-FIBULAR SYNDESMOTIC JOINT IN UNINJURED PATIENTS?

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Abstract

Background:

The syndesmosis is a crucial component for the ankle joint as any injury to it can immobilize a person. The ultimate goal of treatment is to restore the syndesmosis and ankle joint to their respective pre-injury, anatomic alignments. Few studies have attempted to characterize normal syndesmotic joints. Many of these studies have had certain limitations: small population size, minimal diversity in subject demographics, and very few raters taking part in data collection. The purpose of this study is to review a normal distal tibiofibular syndesmosis and characterize the parameters of an uninjured joint using both computed tomography (CT) and magnetic resonance imaging (MRI).

Methods:

Our study was a retrospective review of 384 CT (269 male, 115 females, age: 18-80 years) and 220 MRI (77 male, 143 females, age: 18-75 years) exams of the lower extremity. Exclusion criteria included pediatric patients, previous injury, surgery, or chronic disease of the ankle. Measurements were based on the width of the syndesmotic joint 1 cm above the tibiotalar joint. Five intervals were measured. The first two were tangential lines from the anterior (ant) and posterior (post) peripheral aspects of the tibiofibular joint. The third was defined centrally (middle) and the last two were midpoints (ant-middle and middle-post). Measurements were compared using descriptive and inferential (t-test, one-way ANOVA) statistical analyses in context of age and gender.

Results:

The overall population (n=604, CT and MRI) demonstrated the following measurements: ant (5.2±1.9 mm), ant-middle (2.6±1.1 mm), middle (2.9±1.2 mm), middle-post (3.6±1.2 mm), post (7.6±2.2 mm). The male intervals were larger compared to females (both CT and MRI), with statistical significance noted in the middle-post ($P < 0.02$) and post ($P < 0.02$) intervals. The differences between genders became larger moving more posterior (ant: 0.2 mm, ant-middle: 0.2 mm, middle: 0.2 mm, middle-post: 0.3 mm, post: 0.6 mm). Comparing age groups showed there was a significant difference ($P < 0.03$). The general trend demonstrated decreasing syndesmotic interval size with increasing age. This can be seen with the extremes of age (18-29 years vs. greater than 60 years) which showed a decrease by greater than 0.5 mm for all values.

Conclusions:

Of the values measured, the middle-post interval demonstrated statistical significance in the gender and age-based differences. Therefore, the middle-post syndesmotic interval may be considered less than 4.8 mm in the uninjured ankle with variations based on gender (± 0.3mm) and age (±0.5mm). The reported values can be referenced after surgery to assess for appropriate reduction and normal alignment. By characterizing the physiological profile of the syndesmotic joint, this study helps define a general baseline for the uninjured ankle.

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Introduction and Significance

Background

Ankle injuries are exceedingly common and one of the primary reasons for visits to urgent cares and emergency rooms. The severity of the injury depends on the location, clinical signs, and functional loss. In terms of location, there are three main regions of focus, which include the lateral, medial, and superior (high) aspects of the ankle. High ankle or syndesmotic injuries occur in 8-13% of all ankle-related injuries and are often associated with significant morbidity.[1]

Understanding the anatomy is crucial in diagnosing syndesmotic injuries. The tibia and fibula represent two bones in the lower leg located directly above the ankle. The articulation of these two bones is referred to as the syndesmosis. By definition, the syndesmosis is referred to as a joint and consists of characteristics seen in other joints. However, there is no motion seen in this joint, and its main function is to provide stability and support to the ankle.[2]

The syndesmosis is a crucial component for the ankle joint as any injury to it can cause pain and instability, which can lead to complete immobilization. The most common method of injury to the syndesmosis is by excessively twisting or rotating the ankle.[2] The ligaments (interosseous tibiofibular ligament, the anterior tibiofibular ligament, and the posterior tibiofibular ligament) that support the syndesmosis can be stretched or torn, leading to an injury.[2] Therefore, when patients suffer injuries to this critical complex, the primary goal is to fix or reduce the joint using either surgical or conservative approaches. For patients requiring surgery, there are two main types of surgeries that can accomplish this, including screw fixation and a suture-button implant. Both surgeries have the ultimate goal of restoring the syndesmosis and ankle joint to their pre-injury, anatomic alignment. Without proper alignment of the ankle joint, poor functional outcomes and possibly post-injury arthritis may develop.[3,4] Therefore, accuracy in alignment is both crucial and difficult for obtaining optimal clinical outcomes.[2]

Rationale/Goal

Previous studies have attempted to characterize the profiles for uninjured syndesmotic joints. However, these studies have had limited patients for their datasets. For example, the study conducted by Mendelsohn et al.[5] only had 38 patients in their dataset. With such a limited amount of data, it is difficult to determine whether or not the profiling of the syndesmosis is truly accurate. Another potential problem with the study was that the population was predominantly male. Having a balanced study is crucial to identifying any potential differences between genders. In addition, many other studies have analyzed the efficacy of surgical methods on the syndesmotic joint in human cadavers.[2,4,6-8] These studies primarily focused on mechanical properties, which relied heavily on the stability of the joint. Although this may offer helpful post-operative results, *in vivo* studies can help account for daily stresses and biological impacts on the joint, thereby giving surgeons a more reliable source of information. Finally, previous studies that have reported average, normative values have had considerable amount of variation as can be seen in Table 1.[9-11]

This current study uses both computed tomography (CT) and magnetic resonance imaging (MRI) to assess the syndesmotic joint. CT is a frequently used imaging technique for syndesmotic joints. No previous studies have looked at the intervals of a normal syndesmosis in adults using MRI. The inclusion of MRI allows improved visualization of the syndesmosis, which can improve the ability to characterize variable parameters.[2]

Hypothesis

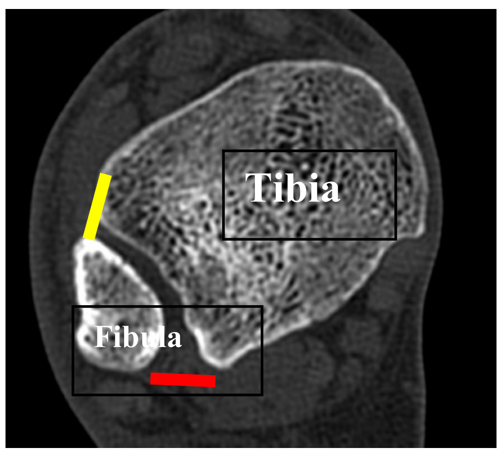
In order to assess the efficacy of the surgeries related to syndesmotic joints, it is vital to characterize the joint in its uninjured form. One form of quantifiable measurement consists of the space or width between the joint. Multiple studies have identified the average interval for the anterior and posterior aspects 10 mm superior to the joint line. It is hypothesized that the normal, uninjured distal tibiofibular joint will have average width measurements less than 10 mm.[5,9-11]

TABLE 1: Published studies with reported average values of anterior and posterior intervals (width).

Study	Anterior Width	Posterior Width
Lepojarvi et al. (n=64)	2.8 ± 0.09 mm (range: 0.9-5.3)	5.1 ± 0.15 mm (range: 2.7-9.1)
Nault et al. (n=100)	4 ± 1 mm (range: 1.5-6.4)	8 ± 1.7 mm (range: 2.1-11.5)
Warner et al. (n=155)	4.46 ± 0.97 mm (range: 2.50-9.53)	8.80 ± 1.66 mm (range: 4.94-12.81)

*Range shown represents the **full range** of values**.**

***CT image of ankle joint below demonstrating where anterior (yellow line) and posterior (red line) intervals measured in studies from table 1**



Axial CT image of ankle joint 1 cm above plafond.

Materials and Methods

Study Design and Population:

This was a retrospective, IRB-approved study that utilized imaging data from the database at Maricopa Integrated Health System for all eligible patients (see Table 2 for enrollment criteria) from 2011-2016. Adults aged >18 years who presented to MIHS for a CT or MRI of the leg, foot, or ankle were included in the study. In order to search for these potential patients, the following search keywords used: CT foot, CT ankle, CT leg, MRI foot, MRI ankle, and MRI leg. The following data were collected for analysis: age, gender, medical conditions, past medical history, and five width measurements. Exclusion criteria included any previous trauma or injury to the ankle joint, and/or any chronic disease that may affect the integrity of the joint. Patient identifiers and data storage were both in accordance with HIPAA compliant methods.

Enrollment Criteria:

Patients were subjected to inclusion and exclusion criteria prior to being enrolled in the study (see Table 2).

Study Protocol:

Seven examiners (three resident physicians and four medical students) reviewed CT images independently using the search keywords mentioned above. One examiner (resident physician) reviewed MRI independently. All seven examiners were provided with identical orientation and training to the protocol prior to initiation of this study. Once a potential image was found, each examiner reviewed for any potential exclusion criteria including surgical hardware, indications of current/previous injury, and/or distortions of image. Once the image passed this threshold, the measurement process started with first obtaining the coronal CT or MR image. Using a ruler tool from the native imaging program, a 1 cm line was drawn above plafond (tibiotalar joint or talar dome). From this measurement, the corresponding axial or transverse image was obtained. Measurements were based on the space (width) of the distal syndesmotic joint using this axial image. Five length (mm) measurements were taken. The first two were tangential lines drawn from the anterior (ant) and posterior (post) peripheral aspects of the tibiofibular joint. The third was the central (middle) width halfway between ant and post. The last two were the midpoint lines between the central and peripheral lines (ant-middle and middle-post). See Figures 2-3 for visual clarification on anatomy and location. Two of the five (ant & post) measurements are adopted from previous studies.[9-11] The addition of ant-middle, middle, and post-middle measurements allows for a more comprehensive profile of the distal syndesmosis as the spacing moving anterior-to-posterior is not universally uniform.[9-11] The inclusion of these three extra intervals also allows for a complete description of the distal syndesmosis. The measurements along with the patient information were recorded in Microsoft Excel®.

Result Interpretation and Statistical Analysis:

Measurements were compared using descriptive statistical analyses in context of age groups, gender, and modality of imaging. Descriptive parameters included mean, median, and standard deviation. A two-sample t-test was used to compare gender and modality of imaging (significance set at $P < 0.05$). In addition, a 1-way ANOVA was used to compare age groups (18-29, 30-39, 40-49, 50-59, and >60 yrs).

Interobserver agreement was analyzed using the intraclass correlation coefficient (ICC) to test for reliability of the measurements. ICC values were evaluated using the Koo et. al reliability index: less than 0.5, poor; 0.5-0.75, moderate; 0.75-0.9, good; and greater than 0.90, excellent reliability.[12] In order to compute the ICC, all raters reviewed the same, randomized 50 CT scans. The interval values from this were then utilized to test reliability. The Wilcoxon Rank Sum test was used to compare the average interval values between gender, age, and modality.

TABLE 2: ENROLLMENT CRITERIA

Inclusion Criteria
1. Patients age >18 years
2. Both male and female patients
3. Obtained MRI or CT of ankle (left or right)

Exclusion Criteria
1. Patient age < 18 years
2. Significant acute or chronic trauma/injury to ankle including fractures and/or ligamentous tears
3. Previous history of ankle surgery
4. Presence of hardware including screws and/or plates indicating previous reduction
5. Indications of chronic disease on imaging
6. Improper positioning of leg during image scan

FIGURE 1: PROTOCOL SUMMARY

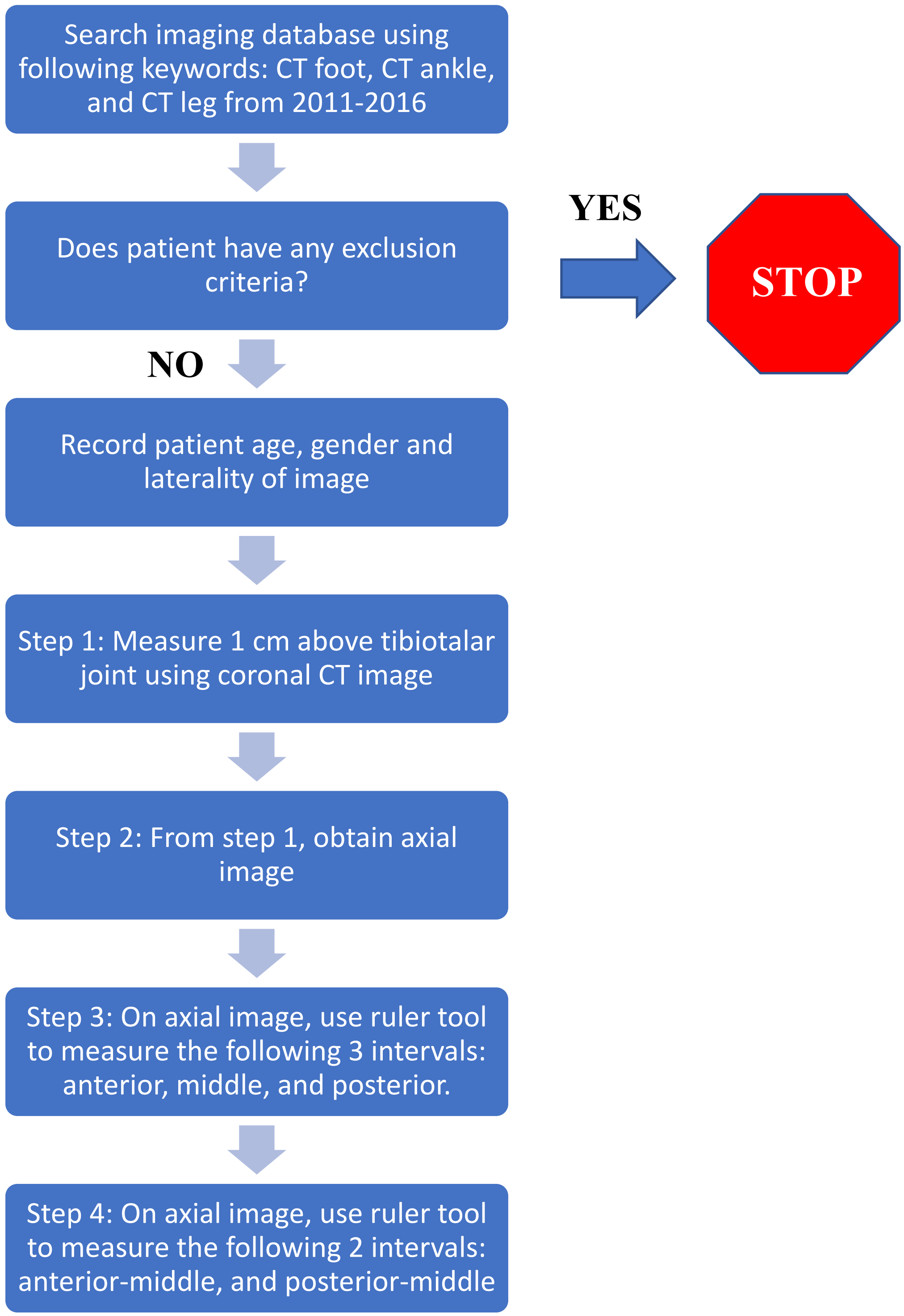
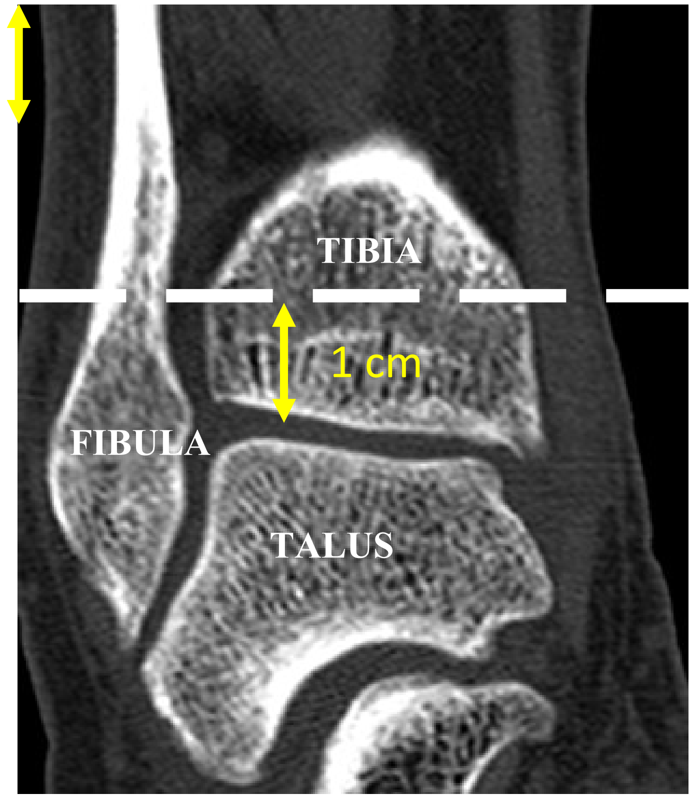
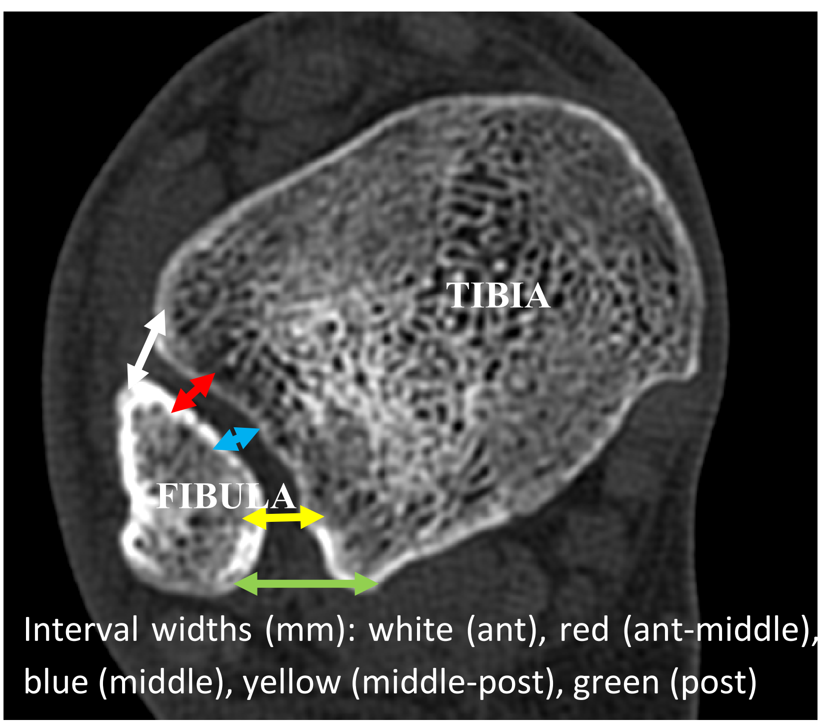


FIGURE 2: CT IMAGES DEMONSTRATING ANATOMY AND LOCATION OF MEASUREMENTS

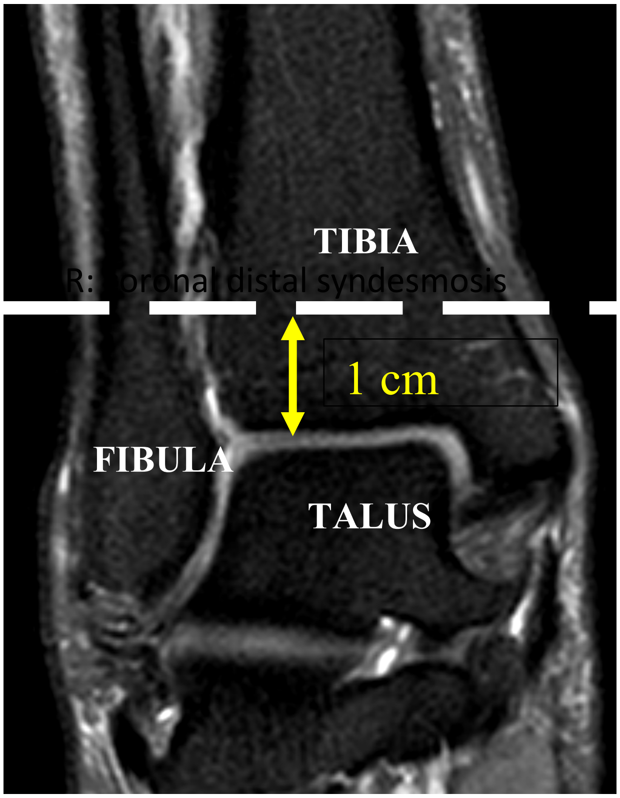


CT: coronal distal syndesmosis

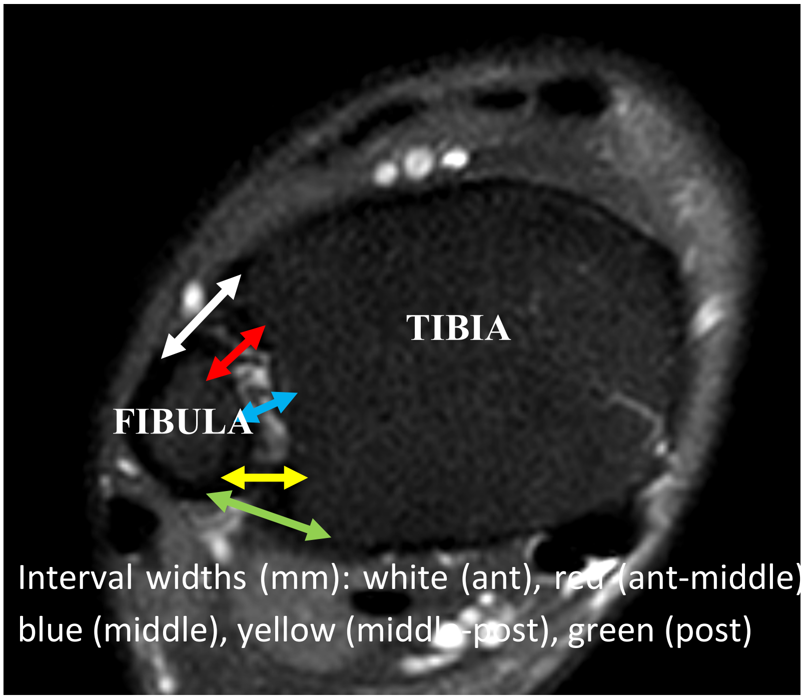


CT: transverse distal syndesmosis 1 cm above tibiotalar joint

FIGURE 3: MR IMAGES DEMONSTRATING ANATOMY AND LOCATION OF MEASUREMENTS



MR: coronal distal syndesmosis



MR: transverse distal syndesmosis 1 cm above tibiotalar joint

Results

A total of 604 individual subjects were selected after applying the inclusion/exclusion criteria. 384 (269 male, 115 females) of the subjects had a CT completed and 220 (77 male, 143 females) had a MR obtained. The age for patient with CT ranged from 18-80 years old and those with MRI ranged from 18-75 years old. Across both modalities, the age range with most subjects was 40-49 years old.

Table 3 demonstrates the average interval values: ant (5.2±1.9 mm), ant-middle (2.6±1.1 mm), middle (2.9±1.2 mm), middle-post (3.6±1.2 mm), post (7.6±2.2 mm). Comparing CT to MRI showed ant (5.4±2.1 vs. 4.9±1.4 mm), ant-middle (2.7±1.2 vs. 2.4 ±0.8 mm), middle (3.0± 1.3 vs. 3.03± 1.0 mm), middle-post (3.5± 1.3 vs. 3.75± 1.03 mm), post (7.4±2.5 vs. 7.9± 1.7 mm). All values when comparing CT vs. MRI were statistically different except for the middle measurement (P = <0.001, <0.001, 0.65, 0.02, 0.01, in order from ant to post). This can further be seen in Figure 5, which shows no significant difference in the middle interval value.

Using CT and MRI to compare genders showed all measurements except for middle-post and post, were not significantly different (P = 0.48, 0.21, 0.10, 0.02, 0.02, in order from ant to post). Similar results were seen comparing genders using MRI (P =0.31, 0.73, 0.4, 0.01, 0.01). Figure 6 demonstrates all of the average interval values for both modalities. Although not statistically significant, observationally males had larger interval spacing. The differences between genders became larger moving more posterior (ant: 0.2 mm, ant-middle: 0.2 mm, middle: 0.2 mm, middle-post: 0.3 mm, post: 0.6 mm).

When comparing different age groups using both CT and MRI, there was a significant difference between all measurements (P= 0.03, 0.002, <0.001, 0.003. 0.007, in order from ant to post). Figure 7 highlights all of the age groups that were compared. Observationally, measurements trended downwards with increase in age. This trend is especially apparent when comparing the age extremes (i.e. 18-29 years vs. > 60 years), which showed a decrease by greater than 0.5 mm for all values

Inter-rater reliability was measured using ICC values for the individual interval measurements. The following shows the ICC values ranges for each interval: ant (0.16-0.58), ant-middle (0.17-0.60), middle (0.30-0.53), post-middle (0.33-0.69), post (0.05-0.57). Using the Koo et al. classification system, each interval measurement ranged from poor-moderate reliability.

FIGURE 4: OVERALL PATIENT DEMOGRAPHICS

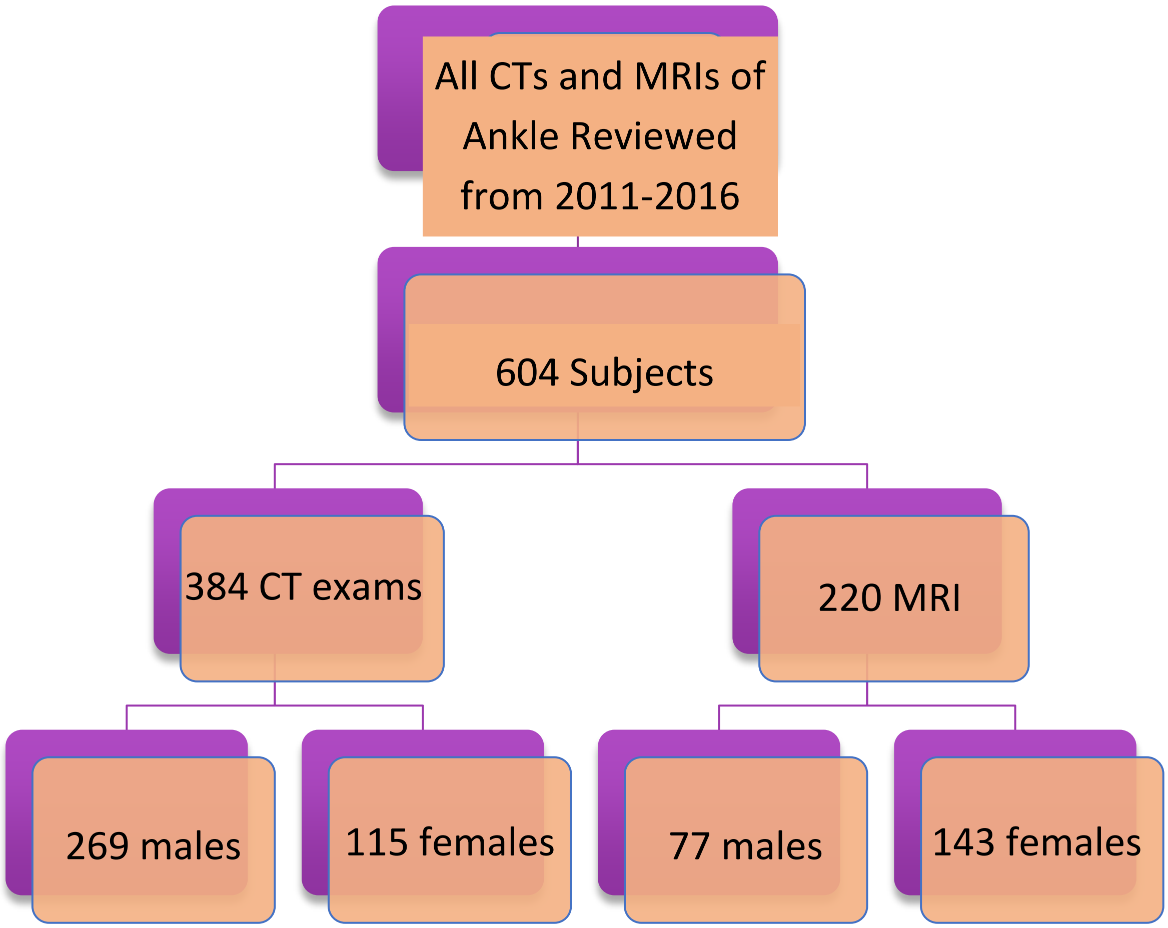


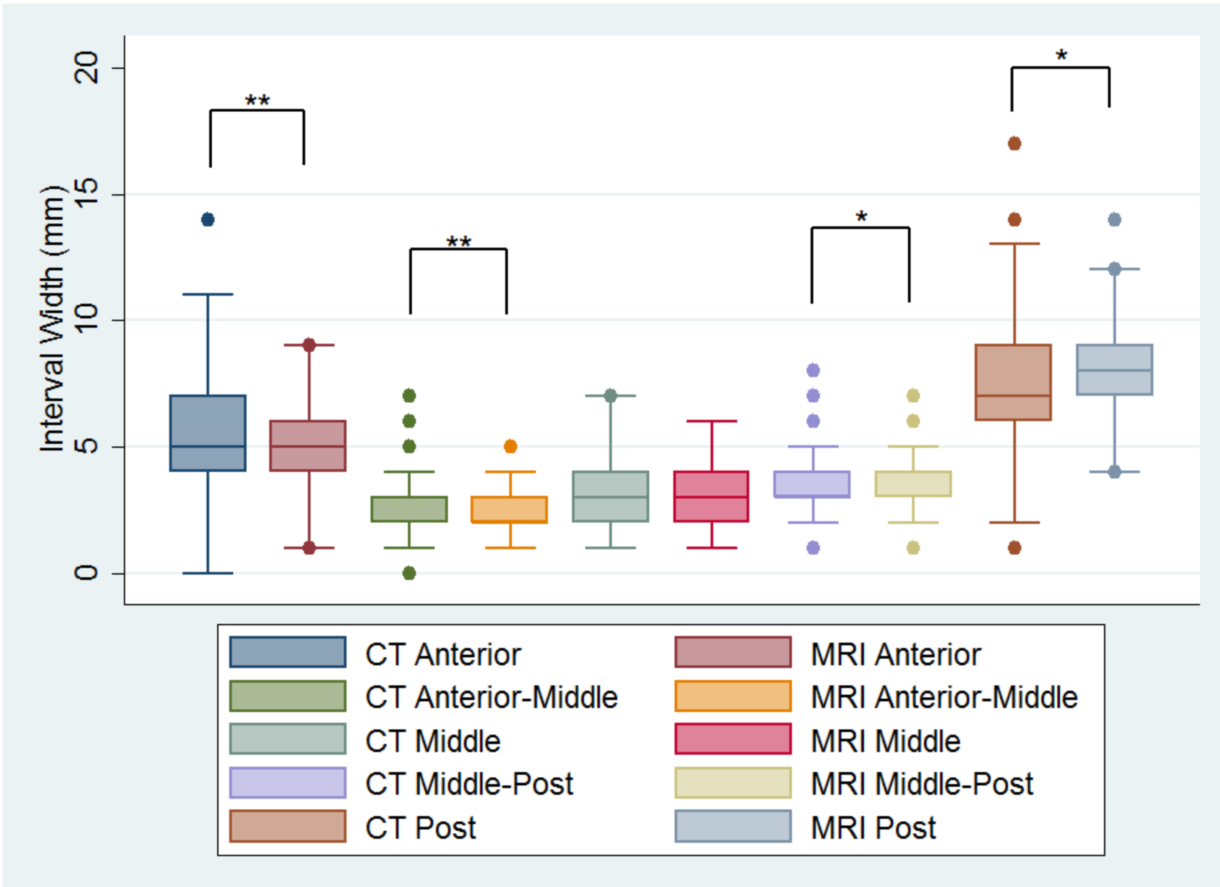
TABLE 3: AVERAGE INTERVAL VALUES AT POPULATION LEVEL

Intervals	CT (mm)	MRI (mm)
Ant	5.42 ± 2.07	4.89 ± 1.37
Ant-Middle	2.74 ± 1.21	2.36 ± 0.83
Middle	2.98 ± 1.30	3.03 ± 0.99
Middle-post	3.50 ± 1.26	3.75 ± 1.04
Post	7.39 ± 2.47	7.87 ± 1.68

******P-values: ant (p < 0.001), ant-middle (p<0.001), middle (p =0.65), middle-post (p= 0.02), post (p=0.01)***

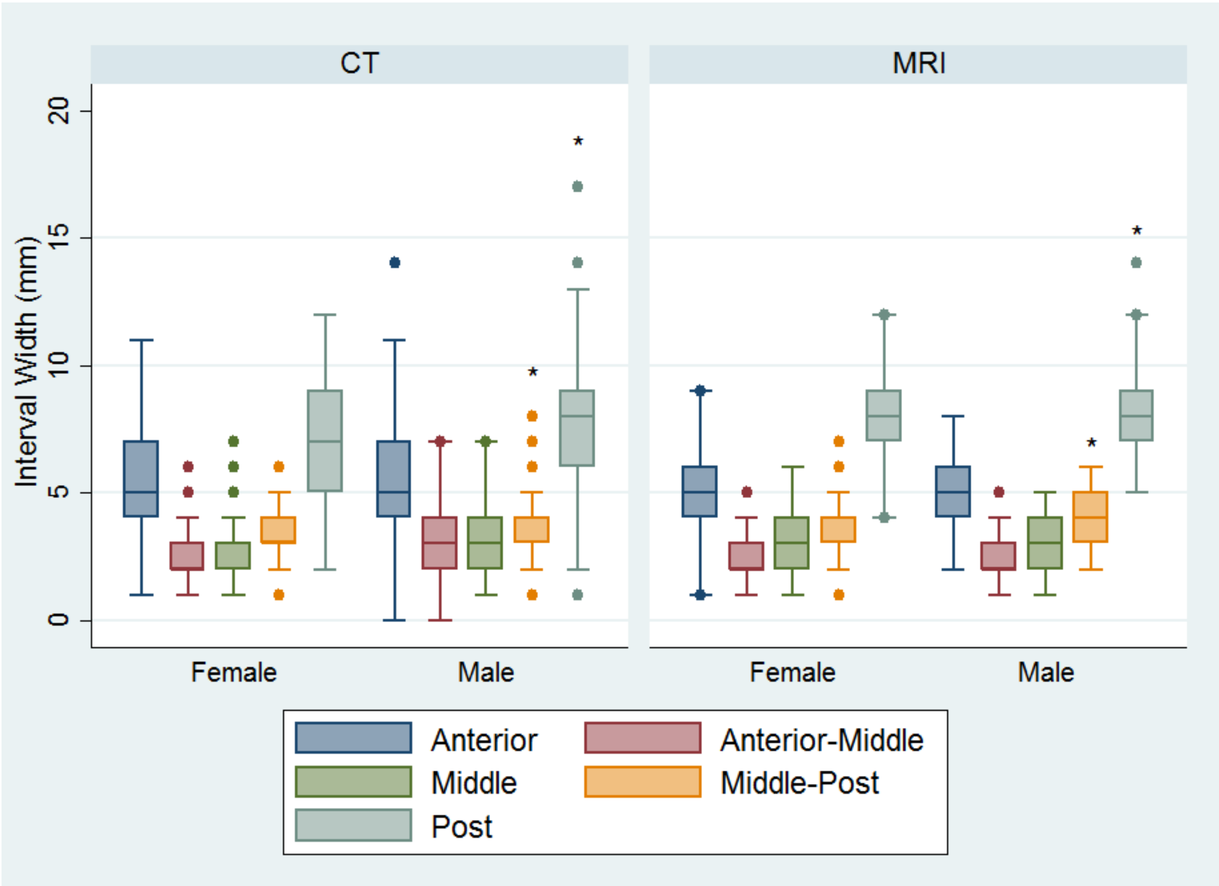
Comparison of average interval values between modalities at the population level

FIGURE 5: AVERAGE INTERVAL VALUES BETWEEN CT AND MRI



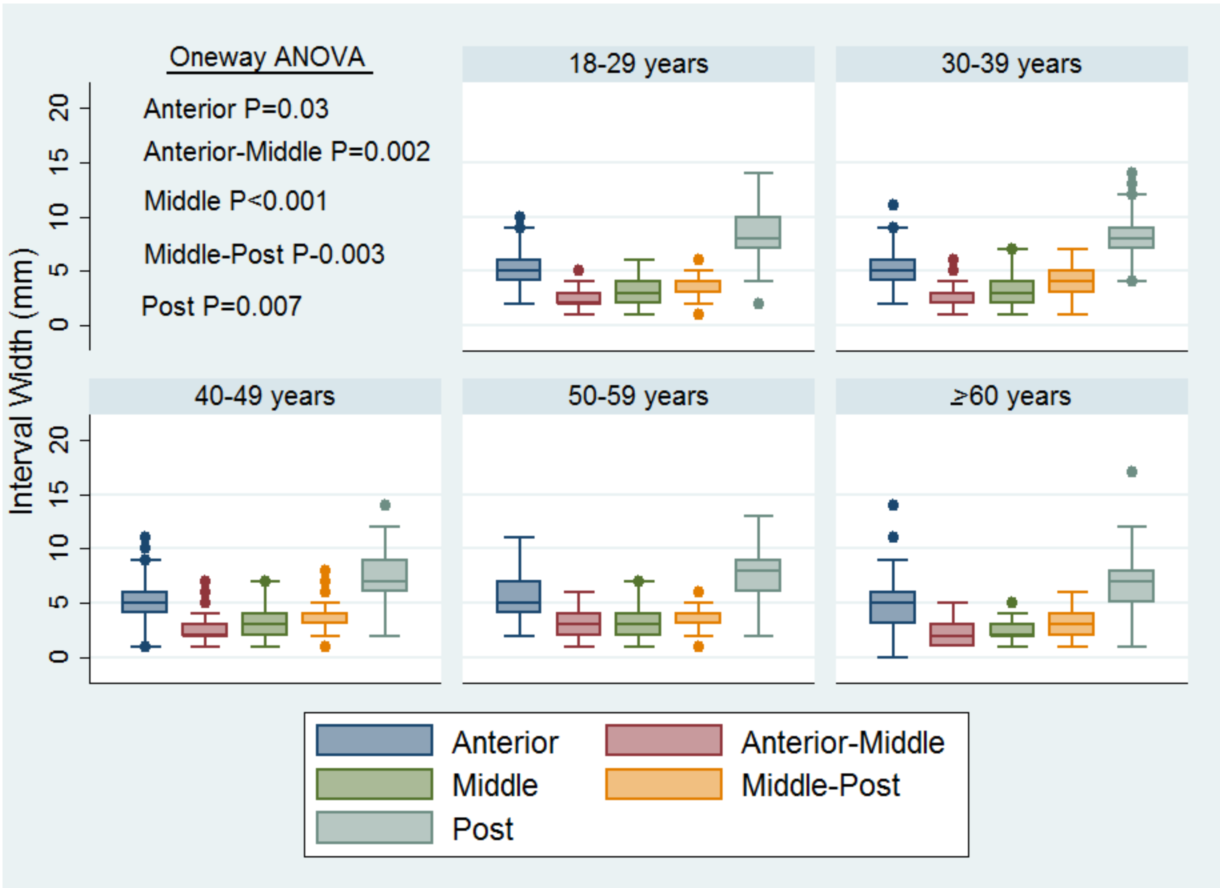
Wilcoxon Rank Sum test used to compare modalities (* indicated p <0.05 and ** indicates p <0.001)

FIGURE 6: AVERAGE INTERVAL VALUES BETWEEN GENDER FOR BOTH CT AND MRI



Wilcoxon Rank Sum test used to compare modalities (* indicated p <0.05 and ** indicates p <0.001)

FIGURE 7: AVERAGE INTERVAL VALUES BETWEEN AGE GROUPS



Discussion

Ankle injuries remain some of the most common reasons for visiting an urgent care and emergency room. The location of the injury can determine the severity and type of treatment needed. Injury to the superior portion of ankle joint ("high-ankle") can be quite detrimental as it can disrupt the syndesmotic complex. As previously stated, the syndesmosis is a crucial component for the ankle joint as any injury to it can immobilize a person. For serious injuries, this can require surgical intervention with the ultimate goal of restoring the syndesmosis and ankle joint to their pre-injury, anatomic alignment.

There are currently very limited studies that have characterized the distal tibiofibular syndesmotic joint.[9-11] Even with the limited studies available, many of them consisted of small cohorts of subjects, thereby questioning the accuracy and reliability of the studies. Most available studies utilized CT imaging as the primary modality for analysis, and none with MRI. By providing parameters and standardizing a profile for a normal, uninjured syndesmotic joint using MRI, it provides clinicians the ability to use the MRI modality without the need to perform further imaging. This allows for quicker and more efficient analysis of surgical success, as well as cost benefits. In addition, MRI provides higher resolution compared to CT. Having this advantage is crucial to clinicians in assessing complicated cases with increased precision.

This study highlighted that there is one reliable form of measurement available for assessing post-surgical success: the middle interval. The meaning of reliable in this context is that this interval measurement was the most reproducible value between modalities (i.e. CT and MRI) and raters. It also showed some variations between gender. The bones in males tends to be larger than their female counterparts. As such, the overall contact between the tibia and fibula can be less, leading to increased spacing within the ankle joint. Of note, a difference seen between genders does not indicate an advantage or disadvantage. It is simply an observational finding that can help accurately stratify a patient when assessing post-surgical success. Another trend was seen in patients of different ages. It was noticed that with increased age, there was less space between the bones comprising the syndesmosis. The main reason for this can be attributed to the progress degenerative changes that occur with increasing age.

Once these trends were discovered, it was important to determine how to stratify the middle value for a specific individual. Focusing on age first, it was found that for patients aged 18-59 years, the middle value was approximately 3.1$\pm$ 2 mm (2*SD) and those >60 years were approximately 2.5 $\pm$ 2 mm (2*SD). Because of this significant difference in values ($p < 0.001$), this was a clear marker for first step in classifying the middle value. Second, after analyzing the middle values for gender, it was discovered that the variation between the two was based on $\pm$ 0.3mm (male values found to be 0.3mm larger than females). This difference would be added or subtracted from the patient based on his/her age (e.g. if patient is <60 years and female, then 0.3mm would be subtracted from 3.1mm). Using this classification criteria, a comprehensive table of the middle values for a specific individual was created (Table 4).

There were a few limitations of this study that must be addressed. One, height and weight were not considered as part of this study. This may be important, because it has been established that with increased weight, the progression of osteoarthritis becomes more rapid secondary to excessive joint loading.[13] Second, systemic conditions such as diabetes mellitus and autoinflammatory conditions were not assessed which may also lead to accelerated degeneration.

The major weakness of this study includes the interobserver reliability. Although every rater was given identical training and orientation to the protocol, there was poor to moderate agreement on the measurements. One possible reason for this is that although a clear definition of the plafond or distal tibiotalar joint was given, there was potential for subjectivity as no two subjects have identical anatomy. One rater may consider the segment closer to the talus as the starting point, while the another prefers the tibial segment. The second reason relates that subjectivity to the actual measurements taken within the syndesmosis. Again, clear definitions were given, however one may perceive the starting “peripheral” aspect of a bone to be in a different location than another rater.

Future directions of this study include improving the interobserver agreement during the second phase. One possible method to combat this is to provide orientation to all raters in one sitting. This would allow assurance that the same definitions and examples are provided. In addition, an identical set of patients can be provided to each rater before initiating data collection to determine if there are major discrepancies early on. A second phase of this study will include a prospective analysis of how the ankle joint is characterized in patients suffering from syndesmotic injuries post-reduction. In addition, other helpful parameters such as the tibial torsional angle may be measured as well.

Conclusion

The middle interval demonstrated statistical significance in the gender and age-based differences. Therefore, the middle interval may be considered less than 5.5 mm* in the uninjured ankle with variations based on gender and age (see Table 4 below). The reported values can be referenced post-surgery to assess for appropriate reduction and normal alignment.

TABLE 4: MIDDLE INTERVAL VALUES STRATIFIED BY AGE AND GENDER

Gender / Age	Male	Female
<59 years	5.4 mm	4.8 mm
>60 years	4.8 mm	4.2 mm * + 2SD (SD =1 mm)

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